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Development and Validation of Bayesian Network Method for Decision-Support System of Insect-Pest Management in Tomato

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Abstract— Bayesian Network (BN), a probabilistic reasoning approach have been widely used in ecological decision-making to deal with uncertain information nevertheless, very few instances of its usage in crop pest management. This paper focuses on how to deal with uncertain agro-ecological information for decision–making in pest management. In the study, a Bayesian network was developed for selecting appropriate management option of fruit borer (*Helicoverpa armigera*) and leaf minor (*Liriomyza trifolii*), key insect-pest of tomato based on the tentative agro-ecological information besides crop condition that farmers provided. Validation of the method resulted in 76% accuracy for fruit borer and 82% for leaf minor. Application of the method thus developed in Decision Support Systems (DSSs) of agriculture with applies Information and Communication Technology (ICT) would automate and speed up the process of providing insect-pest management decision support to the farmers. Thus, it will not only save the crop worth crores of rupees but also help in reduction of excessive and irrational usage of pesticides thus saving the environment and human health.

Keywords— Fruit borer, Leaf minor, Tomato, Decision-making, ICT, DSS, Pest Management

I. Introduction

Tomato (*Lycopersicon esculentum* L.) is one of the most important vegetable crop which is widely grown in the northern plains of India [24]. It is one of the most versatile vegetable crops with wide usage in Indian culinary. Annual production of tomato in India is 86 lakh tons which is 8.5% of the total vegetable production. Tomato occupies an area of 0.87 m. ha [16] but its productivity remains very low [9]. Tomato yield is significantly hampered by several pests (insects and diseases). Average incidence of pests in farmers' fields varies from 10 to 20 % [7]. In the absence of knowledge and expertise, large farming community is over-dependent on pesticide dealers for support on pest management decision-making in the country, which results in excessive and irrational use of chemicals for the pest control. This not only degrades the environment, but also affects human health due to pesticide residue in vegetables.

The core of pest management framework is the decision-making [29]. The major decision that concerns the farmers for pest management is "whether and what pest management actions are required". In the absence of knowledge and expertise, farmers are over-dependent on pesticide dealers for pest management decision-support in the country, which results in excessive, injudicious and irrational use of chemicals for the pest control. This not only degrades the environment, but also affects human health due to the retention of pesticide residues in vegetables [18]. Presently, agricultural Decision Support Systems (DSSs) available in the country which use Information and Communication Technology (ICT) provide pest management decision-support to the farmers on the basis of the pest Economic Threshold Level (ETL) assessed through analysis of scientifically observed quantitative pest activity information captured from farmers' fields [19]. However in current pest management, decision-making depends upon a large range of pest relevant agro-ecological information [13], beside pest activity. Nevertheless, a large section of the farming community is neither qualified nor trained to obtain this kind of information rather can obtain qualitative information consisting of uncertainty. However there are no methods available to deal with this kind of uncertain or tentative agro-ecological information for selecting appropriate pest management option to be advised to the farmers. Therefore to overcome this problem, Bayesian network (BN) has been employed for selection of pest management option on the basis of tentative agro-ecological information provided by the farmers. Bayesian network has been effectively used in ecological decision-making [1], but only few experiences of its usage have been conducted in pest management. BN has also been used in the field of education [4]

Application of innovative methods in ICT based DSSs of agriculture can facilitate and speed up the process of providing decision-support to the farmers on selection of appropriate pest management options based on the tentative pest relevant information, they provide. This can either result in saving crop worth crores of rupees or in non-application of intervention saving the cost of intervention involved and thus saving the environment [18].

II. DECISION-MAKING IN PEST MANAGEMENT

Decision-making starts with the identification of a problem, which requires the collection of all relevant information for critical analysis of the problem. The analysis leads to development of a set of available alternative courses of actions to solve the problem; only realistic solutions should be selected considering multiple criteria e.g. effectiveness, benefits, costs and the constraints. Based on this analysis, the best solution is selected and the decision is converted into an action [29]. Compared to other economic activities, decision-making in crop protection have received very little attention [25]. Decision-making in pest management is a dynamic and complex process (Figure 1) requiring much more knowledge and expertise.

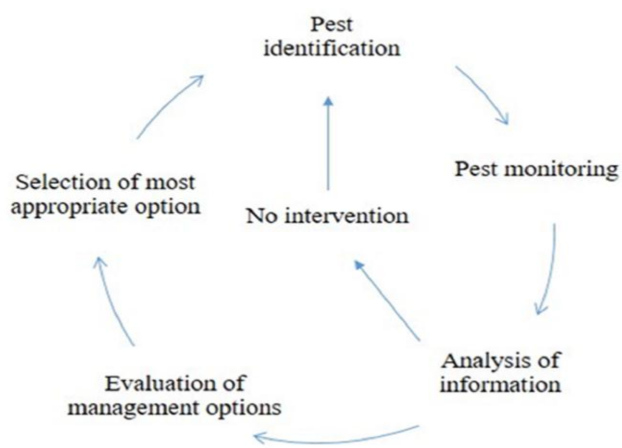

Figure 1. Decision making in pest management

Effective pest management needs detailed and careful management of field activities at strategic, tactical, and operational levels. Strategic decisions such as crop rotation, variety replacement etc. are made at the field and crop level whereas tactical decisions such as pest outbreak which requires management intervention are made on the basis of what is happening in the field, obtained through regular crop-field monitoring. The most important tactical decision that concerns the farmers is 'whether and what pest management option is required'. Pest management works effectively if the farmer is able to timely select the most appropriate pest management option which follows the pest management principles. Whenever the farmer notices any pest activity while monitoring his/her field, he/she needs to scientifically observe the pest activity and other relevant information necessary for pest management decision-making. After due analysis of the information observed, first decision to be made is whether pest management action is required and if so, what is the most appropriate option; chemical, biological or physical. In effective pest management, sustainable biological, physical, and other non-chemical methods, which are safer to environment and human health, are preferred to chemical methods [29].

A. Basis of Decision-Making in Pest Management

For several decades, pest Economic Threshold Level (ETL) has been the basis for decision-making on pest management, which requires scientifically observed quantitative information about pest activity from farmers' fields. This is defined as the lowest population density that will cause economic damage [2] at which control measures should be initiated against an increasing pest population to prevent economic damage. It is expressed quantitatively and is calculated based on management cost per hectare, price of the farm produce/ kilogram and expected damage (kilogram/pest). ETL is the best-known and widely used concept for pest management decision-support [14] but there are many reasons for not to use this concept.

In present day pest management emphasizes on agro-ecological situation of farmer field wherein decisions are based on large range of pest relevant information [3] such as crop health, natural enemies, weather etc. beside pest activity. Understanding the intricate interactions in the ecosystem plays an important role in agro-ecological situation based crop-pest management. This not only reduces the usage of chemical pesticide usage but also conserves the environment. Therefore, pest management specialists have realized the limitations of the ETL and gradually shifted towards agro-ecological information based pest management decision-making.

B. Bayesian Network

BNs emerged from research into artificial intelligence, where they were originally developed as a formal means to analyse decision strategies under uncertain conditions [21]. BNs are probabilistic graphical models and consist of 'nodes', that represent a set of random variables, and 'links', that represent their conditional interdependencies (cause-effect relationship) via a directed acyclic graph (DAG) [6], [11]. The values of the nodes are defined in terms of different and mutually exclusive 'states' [23]. A BN can include different types of nodes: 'nature' nodes, 'decision' nodes, and 'utility' nodes. Nature nodes are variables that can be controlled by the decision-maker's actions, and represent the empirical or calculated parameters and the probabilities that various states will occur. Input nodes (i.e., nodes without parents) can either be structured as constants or categorical states with associated marginal probability distributions. A decision node represents control variables or events that can directly be implemented by the decision maker. These nodes typically represent the suite of available management actions. Decision node should always be accompanied by utility node. Utility node represent the value of the decisions or outcomes and can be linked directly to the decision node [15]. Decision nodes do not hav**e** probabilities associated with them. BNs that represent and solve decision problems under uncertainty are also known as Bayesian decision networks [20]. As BNs are causal, they can also be used to calculate the effectiveness of interventions, such as alternative management decisions or policies.

A BN is a pair (G; P) [5], [28], [11] where
G = (V; E) is a DAG whose set of nodes V = {X1, X2…Xn} represents the system variables and set of arcs E represents direct dependencies among the variables;
P is a set of conditional probability distributions containing a conditional probability distribution P (Xi/pa (Xi)) for each variable X given the set of parents pa (Xi) in the graph.
The joint probability distribution over V can be recovered from this set P of conditional probability distributions applying the chain rule as:

$$P(X1, X2\ldots Xn) = \prod_{i}^{n} P\,(Xi/pa\,(Xi)) \quad (1)$$

The process of obtaining the probabilities of a BN can be done either manually, from experts' knowledge on the domain, or automatically, from databases [10].

III. BAYESIAN NETWORK BASED METHOD OF DECISION-SUPPORT FOR MANAGEMENT OF KEY INSECT-PESTS IN TOMATO

In the study, Meteorological Standard Week (MSW) wise data records of pest activity of major insect pests of tomato from 2012-13 to 2015-16, weather features and the population of natural enemies were obtained from the government institution. The data records were collected form ten farms of tomato growing villages in Patiala district belonging to northern plains. The descriptive statistical analysis of the data records further confirmed that fruit borer and leaf minor are the key insect-pests of tomato in the region. Studies have reported a variety of natural enemies attacking these pests at different stages of their life cycle [13]. However, data records revealed scarce population of spiders as the predatory natural enemy found throughout the region. This may be because of the indiscriminate use of chemical pesticides by the farmers.

Correlation analysis of the data records showed maximum temperature as the most significant weather factor affecting the activity of both the insects. In case of borer, fruit damage was positively correlated with maximum temperature (r= 0.5082 and 0.5393) and thus endorsed the earlier findings that temperature is positively associated with the fruit borer activity [26] and 12 - 21 ^{0}C temperature is most favorable for borer activity in tomato [27]. Leaf minor activity too demonstrated positive correlation (r= 0.7738, 0.4268 and 0.8442). As reported earlier, maximum temperature has positive impact on enhancing the leaf minor activity [22]. Higher level of leaf miner infestation is maintained when average temperature ranged from 21.60 - 27.23 ^{0}C [17]. Other weather factors such as Relative humidity (RH) and sunshine did not any show significant and consistent relationship with the activity of these insect-pest.

Thus, based on the above analysis results and the knowledge elicited from literature and domain experts, presence of natural enemies (spiders only), maximum temperature, pest activity, crop health and pest management options were identified as five prominent variables (nodes) of interest and a BN structure of pest management method was established (Figure 2). In the structure, presence of natural enemies and maximum temperature as weather are the parent nodes of pest activity, the child node and pest activity and crop health are the parent nodes for pest management option, the decision node in the structure. The arcs indicated the general direction of cause-effect relationship.

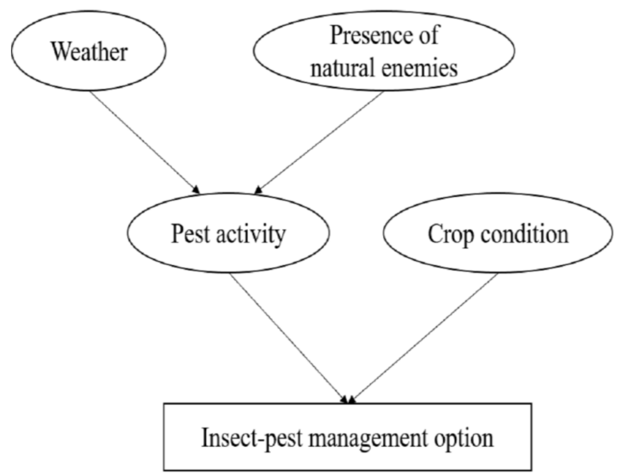

Figure 2. BN structure for selection of pest management option

Once BN structure was established, all the nodes or variables of the method were discretized that Table 1 provides, through analysis of data records and the numerical definitions. CPTs for BN method of identified insect-pests were computed using obtained data records as well as the expert knowledge.

Table 1. Description of the nodes' states in the Bayesian Network

Node name	Definition	State	
		Fruit borer	**Leaf minor**
Weather	Standard weekly maximum temperature	Warm: Greater than or equal to 18 ^{0}C. Cold: Less than 18 ^{0}C	Warm: Greater than or equal to 22 ^{0}C. Cold: Less than 22 ^{0}C

Presence of natural enemies	Plant wise weekly population of spiders.	Moderate: Greater than or equal to 2.0/plant. Low: Less than 2.0/plant	Moderate: Greater than or equal to 2.0/plant. Low: Less than 2.0/plant
Pest activity	Damaged fruits by fruit borer and Mines caused by L. minor on plant leaves	High: >= 4% damaged fruits/plant. Medium: >= 2% and <4% damaged fruits/plant. Low: <2 % damaged fruits/plant	High: >=3 mines/5 leaves/plant. Medium: >=1 and <3 mines/5 leaves/plant. Low: <1 mines/5 leaves/plant
Crop condition	Crop health in the field	Good & Poor (randomized)	Good & Poor (randomized)

Subsequently, BN method for Fruit borer and leaf minor was built using the Netica software (Figure 3 & 4). The relationships in the BN are conditionally probabilistic rather than deterministic, except for the utility node.

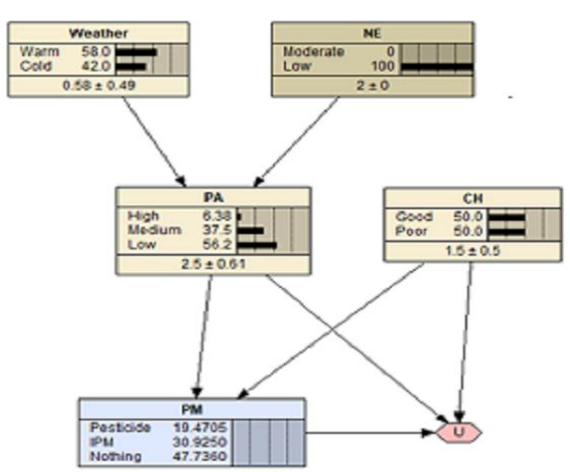

Figure 3. Bayesian network for selection of pest management option for fruit borer

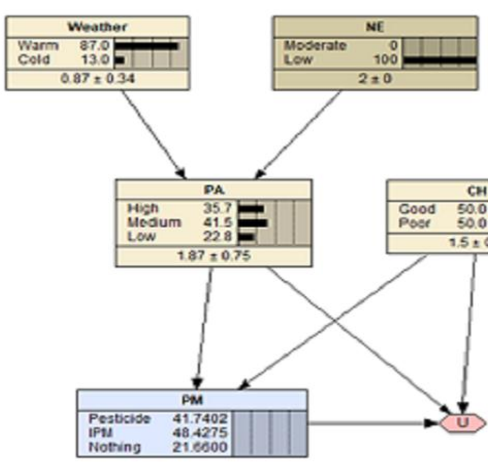

Figure 4. Bayesian network for selection of pest management option for leaf minor

A. Validation of Bayesian Network Method

The validation or evaluation of the method helps to ensure the accuracy and feasibility of the outcome. The method should be validated according to the purpose and objective of the exercise. The accuracy of the method should be tested against empirical data, but in many cases, these data are not available, at least not voluminously. If data on the system are limited or unavailable, qualitative forms of method/model evaluation, such as a peer review, are valuable]. Ideally, the accuracy of the method should be tested with empirical data, but in many studies that use BNs these data are not available, at least not voluminously [8]. Acquisition of empirical data should be seen as a crucial component of model evaluation [12].

To measure the performance accuracy of developed BN, fruit borer and leaf minor pest activity and weather data records from a major tomato growing village i.e. Padhana, Karnal (Haryana) belonging to the selected region were observed during 2017-18. Randomly four farmers' fields were selected from the areas of village prominently growing tomato crop. Validation of the BN helped in finding whether appropriate pest management option has been selected and is feasible to apply the same in the field. The accuracy of the BN was tested against empirical data. To record the output of the developed BN, a small DSS mobile app was developed and loaded into the phones of selected farmers of the region. Farmers provided weekly input values i.e. tentative agro ecological information on temperature and presence of natural enemies and crop condition to the app. Probabilities of pest activity level generated based on above input values and the randomized probabilities of crop condition were propagated through the app to select the appropriate management option as output. At the end of the crop season, these weekly input and output values stored in an excel sheet incorporated into the app were obtained. The app advised pest management option selected based on tentative pest relevant agro-ecological information were compared vis-a-vis pest management option to be applied on the basis of actual quantitative pest activity information scientifically obtained from farmers' fields (Table 2). Pest management options suggested by the method were appropriate in 76% cases of fruit borer and in 82 % cases of leaf minor. The outcome was reasonable and logical. The BN method was also qualitatively evaluated in a meeting involving domain experts, where the method and its results were presented and discussed. The reviewers were satisfied with the results produced by the method as it was intended

Table. 2: Pest management option selected by BN method vis-a-vis based on actual pest activity

MSW	Input values of max. temperature, presence of natural	Probability of pest activity level produced	Output of the method (PM option	Actual pest activity	Appropriate PM option based on actual pest activity

	enemies & crop condition as provided by the farmers	**by the method**	**selected)**		
50	C, L, G	L (75%)	NIR	1.83	NIR
51	C, L, G	L (75%)	NIR	1.47	NIR
52	W, L, G	H - M (81%)	IPM	0.57	NIR
1	C, L, G	L (75%)	NIR	1.16	NIR
2	C, L, G	L (75%)	NIR	0.57	NIR
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50	C, L, G	L (80%)	NIR	0.95	NIR
51	C, L, G	L (80%)	NIR	0.97	NIR
52	C, L, G	L (80%)	NIR	0.93	NIR
1	C, L, G	L (80%)	NIR	0.95	NIR
2	C, L, G	L (80%)	NIR	0.90	NIR
3	W, L, G	M (53%)	IPM	0.72	NIR
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Note: MSW: Meteorological Standard Week, W: Warm, C: Cold, H: High, M: Medium, L: Low, PM: Pest Management, NIR: No intervention required, IPM: Integrated Pest Management

IV. CONCLUSION

In this brief, the BN results found near to satisfactory. The BN presented would be considered as of initial level which could be further updated using much more data. Application of the BN in DSSs of agriculture with applies information and communication technology would automate and speeds up the decision support to the farmers on insect–pest management in tomato crop.

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